

U.S. Patent Application Serial No. 09/995,588
Response dated September 15, 2003
Reply to OA of June 18, 2003

IN THE CLAIMS:

Please amend claim 1 as follows:

1. (Currently Amended): A method of making a micromirror unit from a material substrate having a multi-layer structure including ~~a plurality of silicon layers~~ a first silicon layer, a second silicon layer and at least one intermediate layer, the micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

forming a pre-torsion bar by etching the first silicon layer ~~layers~~, the pre-torsion bar being smaller in thickness than the mirror forming base and held in contact with the intermediate layer; ~~and~~
attaching a third silicon layer to the first silicon layer; and

forming the torsion bar by removing the intermediate layer contacting with the pre-torsion bar.

2. (Original): A method of making a micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

preparing a first material substrate having a multi-layer structure including a first silicon layer, a second silicon layer and an intermediate layer disposed between the first and the second silicon layers, the first silicon layer having a thickness corresponding to a thickness of the torsion bar;

providing a first mask pattern on the first silicon layer to mask a portion of the first silicon layer that is processed into the torsion bar;

performing first etching until the first etching reaches the intermediate layer for forming a pre-torsion bar contacting with the intermediate layer;

attaching a third silicon layer to the first silicon layer for forming a second material substrate incorporating the pre-torsion bar;

subjecting the second silicon layer to second etching by using a second mask pattern arranged to avoid a region corresponding to the pre-torsion bar, the second etching being continued until the intermediate layer is exposed;

subjecting the third silicon layer to third etching by using a third mask pattern arranged to avoid a region corresponding to the pre-torsion bar, the third etching being continued until the pre-torsion bar is exposed; and

subjecting the intermediate layer exposed by the second etching to fourth etching for removing the intermediate layer contacting with the pre-torsion bar so that a torsion bar is obtained.

3. (Original): The method according to claim 2, further comprising the step of forming a fourth mask pattern to mask the pre-torsion bar, wherein the fourth mask pattern forming step is performed after the pre-torsion bar is formed in the first material substrate and before the second material substrate is formed.

4. (Original): A method of making a micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

preparing a first material substrate having a multi-layer structure including a first silicon layer, a second silicon layer and an intermediate layer disposed between the first and the second silicon layers, the first silicon layer having a thickness corresponding to a thickness of the torsion bar;

forming a first mask pattern to mask a region of the first silicon layer that is to be processed into the torsion bar;

attaching a third silicon layer to the first silicon layer;

subjecting the second silicon layer to first etching by using a second mask pattern arranged to avoid a region for forming the torsion bar, the first etching being performed until the intermediate layer is exposed;

forming a pre-torsion bar contacting with the intermediate layer by subjecting the third silicon layer to second etching using a third mask pattern arranged to avoid a region for forming the torsion bar, the second etching being continued until the first mask pattern and the intermediate layer are exposed; and

subjecting the intermediate layer exposed by the first etching to third etching for removing the intermediate layer contacting with the pre-torsion bar so that the torsion bar is provided.

5. (Original): A method of making a micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

preparing a material substrate having a multi-layer structure including a first silicon layer,

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a second silicon layer and an intermediate layer disposed between the first and the second silicon layers;

forming a groove in the first silicon layer by subjecting the first silicon layer to first etching using a first mask pattern arranged to avoid a region in which the torsion bar is formed, the first etching being continued until the intermediate layer is exposed;

coating the groove with a silicon material;

subjecting the second silicon layer to second etching using a second mask pattern arranged to cover a region in which the torsion bar is formed, the second etching being continued until the intermediate layer is exposed;

subjecting the intermediate layer exposed by the second etching to third etching performed on a side of the second silicon layer, the third etching being continued until the silicon material applied at the groove is exposed;

performing fourth etching on a side of the second silicon layer to remove the silicon material exposed by the third etching, so that a pre-torsion bar made of the silicon material and contacting with the intermediate layer is obtained; and

forming the torsion bar by removing the intermediate layer contacting with the pre-torsion bar.

6. (Original): A method of making a micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

preparing a material substrate having a multi-layer structure including a first silicon layer, a second silicon layer and an intermediate layer disposed between the first and the second silicon layers;

forming a groove in the first silicon layer by subjecting the first silicon layer to first etching using a first mask pattern arranged to avoid a region in which the torsion bar is formed, the first etching being performed until the intermediate layer is exposed;

coating the groove with a silicon material;

subjecting the silicon material applied at the groove to second etching using a second mask pattern to mask a region in which the torsion bar is formed, the second etching being continued until the intermediate layer is exposed, so that a pre-torsion bar made of the silicon material and contacting with the intermediate layer is obtained;

subjecting the third silicon layer to third etching using a third mask pattern arranged to avoid a region corresponding to the pre-torsion bar, the third etching being performed until the intermediate layer is exposed; and

subjecting the intermediate layer exposed in the third etching to fourth etching for removing the intermediate layer contacting with the pre-torsion bar, so that the torsion bar is obtained.

7. (Original): A method of making a micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

preparing a first material substrate including a first silicon layer;

forming a groove in the first material substrate by first etching using a first mask pattern arranged to avoid a region in which the torsion bar is formed;

coating the groove with an intermediate layer material;

applying a silicon material on the coating of the intermediate layer material to fill the groove;

forming a second material substrate having a multi-layer structure which includes the first material substrate, an intermediate layer covering the groove of the first material substrate and a second silicon layer contacting with the intermediate layer, the second material substrate incorporating a pre-torsion bar that is made of the silicon material and held in contact with the intermediate layer;

subjecting the first silicon layer to second etching using a second mask pattern arranged to avoid a region corresponding to the pre-torsion bar, the second etching being performed until the intermediate layer material applied to the groove is exposed;

subjecting the second silicon layer to third etching using a third mask pattern arranged to avoid a region corresponding to the pre-torsion bar, the third etching being continued until the intermediate layer is exposed; and

subjecting the intermediate layer material exposed in the second etching and the intermediate layer exposed in the third etching to fourth etching for removing the intermediate layer material and the intermediate layer to provide the torsion bar.

8. (Original): A method of making a micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

preparing a first material substrate including a first silicon layer;

subjecting the first material substrate to first etching using a first mask pattern arranged to mask a region to be processed into the torsion bar, the first etching being continued until the etching reaches a depth corresponding to a thickness of the torsion bar;

preparing a second material substrate having a multi-layer structure which includes the first material substrate, an intermediate layer held in contact with an etched surface of the first material substrate and a second silicon layer held in contact with the intermediate layer;

subjecting the second silicon layer to second etching using a second mask pattern arranged to avoid a region in which the torsion bar is formed, the second etching being continued until the intermediate layer is exposed;

subjecting the first silicon layer to third etching using a third mask pattern arranged to avoid a region in which the torsion bar is formed, so that a pre-torsion bar contacting with the intermediate layer is obtained; and

subjecting the intermediate layer exposed in the second etching to fourth etching for removing the intermediate layer contacting with the pre-torsion bar, so that the torsion bar is provided.

9. (Original): A method of making a micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

preparing a material substrate having a multi-layer structure including a first silicon layer, a second silicon layer and an intermediate layer disposed between the first and the second silicon layer;

subjecting the first silicon layer to first etching using a first mask pattern and a second mask pattern, the first mask pattern being arranged to mask a region in which the torsion bar is formed, the second mask pattern being arranged to avoid a region in which the torsion bar is formed, the first etching being continued until the etching reaches a depth corresponding to a thickness of the torsion bar;

removing the first mask pattern;

subjecting the first silicon layer to second etching using the second mask pattern, the second etching being continued until the intermediate layer is exposed, so that a pre-torsion bar contacting with the intermediate layer is obtained;

subjecting the second silicon layer to third etching using a third mask pattern arranged to avoid a region corresponding to the pre-torsion bar, the third etching being continued until the intermediate layer is exposed;

subjecting the intermediate layer exposed in the third etching to fourth etching for removing the intermediate layer contacting with the pre-torsion bar to provide the torsion bar.

10. (Original): A method of making a micromirror unit including a mirror forming base, a frame and a torsion bar, the method comprising the steps of:

preparing a material substrate having a multi-layer structure which includes a first silicon layer, a second silicon layer having a thickness corresponding to a thickness of the torsion bar, a third silicon layer, a first intermediate layer between the first and the second silicon layers, and a second intermediate layer between the second and the third silicon layers;

subjecting the first silicon layer to first etching using a first mask pattern and a second mask pattern, the first mask pattern being arranged to mask a region in which the torsion bar is formed, the second mask pattern being arranged to avoid a region in which the torsion bar is formed, the first etching being continued until the etching reaches a depth corresponding to a thickness of the torsion bar;

removing the first mask pattern;

subjecting the first silicon layer to second etching using the second mask pattern, the second etching being continued until the first intermediate layer is exposed, so that a third mask pattern is formed at the first silicon layer disposed on the first intermediate layer;

subjecting the first intermediate layer exposed in the second etching to third etching using the third mask pattern, the third etching being continued until the second silicon layer is exposed, so that a fourth mask pattern is formed at the first intermediate layer disposed on the second silicon layer;

subjecting the second silicon layer exposed in the third etching to fourth etching using the

fourth mask pattern, the fourth etching being continued until the second intermediate layer is exposed, so that a pre-torsion bar is formed between the first and the second intermediate layers;

subjecting the third silicon layer to fifth etching using a fifth mask pattern arranged to avoid a region corresponding to the pre-torsion bar, the fifth etching being continued until the second intermediate layer is exposed; and

performing sixth etching to the second intermediate layer exposed in the fifth etching and to the first intermediate layer on the pre-torsion bar, so that the first and the second intermediate layers contacting with the pre-torsion bar are removed to provide the torsion bar.

11. (Original): The method according to claim 9 or 10, wherein the second etching forms a comb-teeth electrode at one of the mirror forming base and the frame.

12. (Original): The method according to claim 9 or 10, wherein an etching process other than the second etching forms a comb-teeth electrode at one of the mirror forming base and the frame.

13. (Original): A method of making a micromirror unit including a mirror forming base, frames and a torsion bar, the method comprising the steps of:

preparing a material substrate having a multi-layer structure which includes a first silicon layer, a second silicon layer having a thickness corresponding to a thickness of the torsion bar, a third silicon layer, a first intermediate layer between the first and the second silicon layers, and a second

intermediate layer between the second and the third silicon layers;

subjecting the first silicon layer to first etching using a first mask pattern arranged to avoid a region in which the torsion bar is formed, the first etching being continued until the first intermediate layer is exposed;

forming a second mask pattern on the first intermediate layer exposed in the first etching, the second mask pattern being arranged to mask a region in which the torsion bar is formed;

subjecting the first intermediate layer to second etching using the second mask pattern, the second etching being continued until the second silicon layer is exposed;

removing the first mask pattern;

subjecting the second silicon layer to third etching using the first intermediate layer exposed by the removal of the first mask pattern, the third etching being continued until the second intermediate layer is exposed, so that a pre-torsion bar contacting with the first and the second intermediate layers is obtained;

subjecting the third silicon layer to fourth etching using a third mask pattern arranged to avoid a region corresponding to the pre-torsion bar, the fourth etching being continued until the second intermediate layer is exposed; and

performing fifth etching to the second intermediate layer exposed in the fourth etching and to the first intermediate layer on the pre-torsion bar, so that the first and the second intermediate layers contacting with the pre-torsion bar are removed to provide the torsion bar.

14. (Original): The method according to claim 13, wherein the etching performed to each silicon layer is inductively coupled plasma etching.

15. (Original): The method according to claim 14, wherein the frames include a first frame and a second frame connected to the first frame by the torsion bar.

16. (Withdrawn): A micromirror unit comprising:
a mirror forming base;
frames having a multi-layer structure including a plurality of silicon layers and at least one intermediate layer; and
a torsion bar which is smaller in thickness than the mirror forming base, the torsion bar defining an axis about which the mirror forming base is rotated relative to the frames, the torsion bar having an end connected to a portion of the silicon layers that is held in contact with the intermediate layer.

17. (Withdrawn): The micromirror unit according to claim 16, wherein the frames include a first frame and a second frame each of which includes a silicon layer and an intermediate layer held in contact with the silicon layer, the torsion bar having one end connected to the silicon layer of the first frame and another end connected to the silicon layer of the second frame.

18. (Withdrawn): The micromirror unit according to claim 16, wherein the frames include two intermediate layers between which only one of the silicon layers is disposed, the torsion bar being connected to said one of the silicon layers.

19. (Withdrawn): The micromirror unit according to claim 18, wherein the frames include first and second frames each of which includes two intermediate layers between which only one silicon layer is disposed, the torsion bar having one end connected to said one silicon layer of the first frame and another end connected to said one silicon layer of the second frame.

20. (Withdrawn): The micromirror unit according to claim 16, wherein the intermediate layer is made of an insulating material.

21. (Withdrawn): The micromirror unit according to claim 16, wherein the mirror forming base is provided with a first comb-teeth electrode, the frames being provided with a second comb-teeth electrode cooperating with the first comb-teeth electrode to move the mirror forming base.

22. (Withdrawn): The micromirror unit according to claim 17, wherein the first frame is provided with a third comb-teeth electrode, the second frame being provided with a fourth comb-teeth electrode cooperating with the third comb-teeth electrode to move the first frame and the mirror forming base.